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Design Considerations for Ozone and Acid Aerosol Exposure and Health Investigations The Fairview Lake Summer Camp Photochemical Smog Case Study

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16. ABSTRACT

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The integration of the study design is discussed in detail by reviewing its application to the 1984 - Fairview Lake Camp Study (July 8 to August 4). The features of the camp study are reviewed, including the study population, pulmonary function procedures and analyses, air pollution monitoring instrumentation, and the site characteristics. The pollution exposure data are presented, for ozone and acidic sulfates and examined for the range and distribution concentration. Further information is provided on the intensity and duration of episodes encountered over the course of the study. Episodes occurred which had ozone and acid sulfates, ozone alone, and acid sulfates alone.

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THE DESIGN CONSIDERATIONS FOR OZONE AND ACID AEROSOL EXPOSURE AND HEALTH INVESTIGATIONS: THE FAIRVIEW LAKE SUMMER CAMP — PHOTOCHEMICAL SMOG CASE STUDY

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The health effects associated with ozone and acidic particulate sulfate exposures to active children have been and are being addressed in field epidemiological studies at summar camps in rural areas of the Northeastern U.S. The rationale and study design for studies, which have been conducted in Pennsylvania and New Jersey, are developed and reviewed. As background, results are summarized for human clinical and epidemiological studies and animal studies. These provided the basis for selection of health outcomes measured results from chemical characterization and transport studies are reviewed to define the criteria used for selection of a site which is effected by high ozone and acid species during photochemical smog episodes. The integration of the study design is discussed in detail by reviewing its application to the 1984 — Fairview Lake Camp Study (July 8 to August 4). The features of the camp study are reviewed, including the study population, pulmonary function procedures and analyses, air pollution monitoring instrumentation, and the site characteristics. The pollution exposure data are presented, for ozone and acidic sulfates and examined for the range and distribution concentration. Further information is provided on the intensity and duration of episodes encountered over the course of the study. Episodes occurred which had ozone and acid sulfates, ozone alone, and acid sulfates alone.

Introduction

Outdoor air pollution is comprised of different chemical species. Each will change in concentration spatially and temporally as a result of a number of processes including source strength, chemical reactivity, absorption and reaction on surfaces, and meteorology. Attempts to assess the human exposure and potential health effects of a specific pollutant or variety of pollutants requires:

(1) selection of a population or sensitive subgroup potentially at risk to the effects of chronic or acute exposures.
(2) definition of microenvironments important in estimating and measuring exposures.
(3) selection of the health outcomes to be measured in the study.
(4) definition of the specific physical, chemical or biological markers of exposure.
(5) determination of the appropriate microenvironment and health monitoring strategy.

With the preceding as a framework for designing a

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field based air pollution health effects study, this paper describes the rationale for the examination of acute exposures to summertime photochemical smog episodes and their effects on the respiratory function of children. Smog episodes have been shown to contain ozone, acidic sulfate particles, and a variety of other primary and secondary pollutants. A specific application of the above will be derived from the design of the Summer of 1984 health effects study conducted at a Youth Camp in Fairview Lake, NJ. The discussion will include the lessons learned from New York University (NYU) pilot health effects studies conducted in 1980 and 1982 in Indiana, PA and Mendham, NJ, respectively, that affected the design of the Fairview Lake Study.

Background Information on Smog Episodes

To design a photochemical smog-health effect study, information on the magnitude and duration of the episodic occurrence of photochemically derived pollutants is necessary. A number of studies have been conducted in non-urban areas of the Northeastern U.S. which have characterized the regional distribution of ambient ozone and sulfate. For these studies the pollutants were at times present in concentrations equal to or greater than those found in urban areas during the summer, Stasiuk and Coffey (1974). This phenomenon provided an opportunity to select a site for this study which would be subjected to relatively high concentrations of secondary pollutants while being influenced minimally by industrial sources and other locally generated pollutants.

Elevated ozone episodes in the midwest and northeast US occur in the spring and summer. Each episode is usually associated with an easterly moving high pressure system that initially contained background ozone concentrations ranging from 60 to 100 $\mu g/m^3$. During the first few days, ozone concentrations in certain areas increase to above 160 $\mu g/m^3$. As an episode develops, areas with high precursor emissions continue to have high ozone concentrations, but the total area affected expands, Wolff and Lioy (1980). When the center of high pressure moves just off the east coast, the entire northeast is influenced by the return flow around the system, and concentrations usually greater than 160 $\mu g/m^3$ of transported ozone enter the northeast seaboard. During the peak of an episode, the ozone concentrations can be raised to between 300–400 $\mu g/m^3$ due to ozone generated in the Washington, D.C. to Boston, MA corridor. Thus, the range in daily maximum ozone concentration during the summer varies from 20 to greater than 400 $\mu g/m^3$ at sites in the northeast. The frequency of such elevated ozone episodes varies from year to year. For instance, in 1976 and 1977, the combined total number of ozone episodes was seventeen, Lioy and Samson (1979).

Studies of the persistence of ozone above the nocturnal inversion layer indicate that ozone can be conserved in sufficiently high amounts to exceed 160 $\mu g/m^3$ at downwind rural and urban locations during multi-day accumulations. Ozone existing above the nocturnal inversion also has been observed to enhance the production of sulfuric acid aerosol in power plant and urban plumes, Gillani and Wilson (1980), and Miller and Alkezweeny (1980).

Ambient sulfate studies have been conducted over an extensive geographical area within the Eastern U.S. and Canada, Tong *et al.* (1976) (1983), Lioy *et al.* (1977), Wolff, *et al.* (1979), and Morandi *et al.* (1983). All have shown the regional nature of the summertime sulfate accumulation. The concentrations vary from year to year, but results show the highest occurring in the Ohio Valley and western Pennsylvania with periodic advection to the east. During one episode, July 8–11, 1974, concentrations of sulfate in excess of 45 $\mu g/m^3$ (24 h average) were observed both east and west of the Appalachian Mountains, Hidy *et al.* (1978). Overall results showed that the longest and most regionally extensive occurrences of sulfate greater than 20 $\mu g/m^3$ are observed in the summer, Mueller and Hidy (1983). During August 1976, the New York-New Jersey-Connecticut metropolitan area had peak sulfate levels between 20 and 40 $\mu g/m^3$, Kneip and Lippman (1979).

In recent years, advances in analytical techniques have been extended to the determination of acid SO_4^{2-} species, and most studies conducted through 1985 have been summarized by Lioy and Lippmann (1986). Two studies of special note involved strong acid measured simultaneously but independently in the Eastern U.S. Pierson *et al.* (1980) collected 12 h integrated Total Suspended Particulate (TSP) samples at Allegheny Mountain, PA, for the period July 24 through August 11, 1977. The SO_4^{2-} aerosol at this rural location had a consistent balance between hydrogen ion (H^+) plus ammonium (NH_4^{2+}) and sulfate (SO_4^{2-}). The H^+ was the most abundant cation when SO_4^{2-} was in excess of 12 $\mu g/m^3$. The highest SO_4^{2-} value was greater than 30 $\mu g/m^3$ and was associated with an H^+ concentration of 17 $\mu g/m^3$ (as H_2SO_4). Measurements were made simultaneously at High Point, NJ, Lioy *al.* (1980), and in the interval August 3–9, 1977, a H^+ concentration maximum of 17.8 $\mu g/m^3$ (as H_2SO_4) for a 6 h sample was recorded. This value occurred 12 h later than the peak H^+ at Allegheny Mountain — 320 km to the west. These results indicated that a broad distribution of high strong acid levels can exist in non-urban areas during a haze episode.

To date, summertime studies on acidic aerosol species have been short in duration, but results indicate that H_2SO_4 concentrations in excess of 28 $\mu g/m^3$ (1 h average) can be achieved. Hydrogen ion concentrations expressed as H_2SO_4 equivalent have reached 40

$\mu g/m^3$ (12 h average), Lioy and Lippmann (1986).

In summary, the Northeastern U.S. is affected by episodes in which the ozone concentrations will increase to above 240 $\mu g/m^3$, National Ambient Air Quality Standard (NAAQS), and the acidic sulfate concentrations can sporadically achieve concentrations of 20 $\mu g/m^3$ for greater than 1 h. Therefore, the potential exists for outdoor exposures to occur for large segments of the population in both rural and urban settings, over the course of a summer.

Review of Health Effects of Ozone and Sulfuric Acid

Ozone and sulfuric acid are pollutants of major concern because individually they are capable of producing measurable transient effects on pulmonary function at concentrations which can occur in the ambient air. Furthermore, they may interact synergistically to produce effects greater than those produced by individual exposures. A brief review of the effects produced by exposure to ozone and sulfuric acid at realistic ambient concentrations is presented to provide background and perspective for the design of a summer smog field health study.

Ozone alone

Information on the health effects of oxidant exposure has emerged from controlled studies on humans, NRC (1977) and U.S. EPA (1978). The results of studies reported in earlier years showed reduced pulmonary function in healthy smokers and nonsmokers at rest after exposure to ozone at 740 $\mu g/m^3$ and higher for 2 h. Studies also showed that the effects of ozone exposure on respiratory mechanical function in humans diminish with repeated daily exposures, indicating some form of adaptation, Hackney (1976), Hackney *et al.* (1977a), Hackney *et al.* (1977b), Farrell *et al.* (1979), Folinsbee *et al.* (1980), Kulle *et al.* (1982).

More recently, McDonnell *et al.* (1983) exposed healthy nonsmoking university students for 2.5 h to O_3 at either 0, 240, 360, 480, 600 or 800 $\mu g/m^3$, with vigorous physical activity for 15 min. each 1/2 h. Significant decrements in Forced Vital Capacity (FVC) and Forced Expiratory Volume in one second (FEV_1) were seen in these subjects at all non-zero concentrations with the greatest response increment occurring between 240 and 480 $\mu g/m^3$. When 8- to 11-year-old boys were similarly exposed at 240 $\mu g/m^3$, comparable effects on respiratory function were observed, McDonnell *et al.* (1985).

Kagawa (1983) exposed healthy university students to 0, 300 and 600 $\mu g/m^3$ O_3 for 2 h in a combination body plethysmograph-exposure chamber with a bicycle ergometer. Exercise was 15 min for each 1/2 h, but the level of exercise was lower than in the McDonnell study. Kagawa (1983) found no mechanical function response without exercise. With exercise, he found that the 10 nonsmokers had statistically significant decrements in FVC at 300 $\mu g/m^3$ (0.6%) and a greater effect (1.1%) at 600 $\mu g/m^3$. For five cigarette smokers, there were no significant mechanical function responses to O_3, even with exercise.

Effects of ozone in the presence of other pollutants

In a study by Hazucha and Bates (1975) in Montreal, university students breathed air which had 740 $\mu g/m^3$ O_3 and 962 $\mu g/m^3$ SO_2.They developed significant disturbances in lung function, and experienced throat irritation, coughing, and chest pains. These effects were present after one-half to one hour of exposure to the mixture, and persisted for several hours after exposure. The effects of the mixed gas exposure were considerably more severe than with 740 $\mu g/m^3$ O_3 alone.

The same protocol was repeated by Bell *et al.* (1977) at Rancho Los Amigos Hospital, Downey, CA, on a population which included some of the same Canadians previously studied in Montreal, and volunteers residing in Southern California. The results indicated less severe pulmonary function changes from mixtures of 740 $\mu g/m^3$ O_3 and 962 $\mu g/m^3$ SO_2. Biological adaptation of California residents to chronic pollutant exposure is one possible explanation, since there is much greater day to day variation in the summertime maximums and the season is longer. Another is that in Montreal there were significantly higher concentrations of respirable sulfates (100 to 200 $\mu g/m^3$) in the chamber.

Lebowitz *et al.* (1974) demonstrated a decline in ventilatory function in children and adolescents after outdoor exercise on days of relatively high pollution in Tucson, Arizona. Their air pollution data suggest that the interaction of oxidants and sulfur dioxide and sulfate produced the effect. Recently, Lebowitz *et al.* (1985) published results of a continuation study in both children and adults. The peak expiratory flow was found to be significantly negatively correlated with TSP and ozone for the children. In the adults, smoking had the largst effect, although there was a significant relationship between ozone and peak flow in adults with obstructive lung disease.

Effects of sulfuric acid aerosols on respiratory mechanical function

Attempts to produce significant changes in respiratory function of healthy animals with sulfur oxide aerosols at concentrations of up to 1000 $\mu g/m^3$ have been unsuccessful, except in the guinea pig, Amdur *et al.* (1978a), Amdur *et al.* (1978b). Investigations of possible alterations in the mechanics of ventilation in humans have been performed by several investigators, Amdur *et al.* (1952), Sim and Prattle (1957), Sackner *et al.* (1973), Newhouse *et al.* (1978), Avol *et al.* (1979). For example, Amdur *et al.* (1952) observed increased respiratory rate and decreased tidal volume in healthy persons exposed to particles containing H_2SO_4 with a

particle size of 1.0 μm through a face mask at concentrations ranging from 400 to 5000 $\mu g/m^3$.

A study reporting statistically significant alterations in respiratory mechanical function following inhalation exposures of healthy humans to H_2SO_4 at a concentration of 1000 $\mu g/m^3$ was done by Morrow *et al.* (1979). In a similar study using adult asthmatics, Utell, *et al.* (1979), found that exposure as low as 350 $\mu g/m^3$ of H_2SO_4 produced a significant decrease in Specific Airway Conductance (SG_{aw}). Koenig *et al.* (1981) studied the effects of particles that contained H_2SO_4 and were of 0.5 μm in size on pulmonary mechanics. Ten exercising asthmatic adolescents were exposed to 100 $\mu g/m^3$, and 40% increases in total airway resistance and an 8–9% decrease in $FEV_{1.0}$, were found in the subjects.

Effects of sulfuric acid on particle clearance from the respiratory tract

As summarized by Schlesinger (1985a), a number of different studies have indicated that transient effects on mucocilary clearance can occur in a number of species following single H_2SO_4 exposures as low as 100 $\mu g/m^3$. Results of the single exposure of rabbits indicates that of the three major ambient sulfur oxide aerosols, H_2SO_4 was the most potent in producing changes in the rate of tracheobronchial mucociliary clearance, Schlesinger (1985b). Ammonium sulfate produced no significant change in clearance rate. This is consistent with the studies of Utell, *et al.* (1982), and Utell *et al.* (1983) who found that changes in SG_{aw} were in proportion to the H^+ concentration. Some differences in actual relative effect may be due to difference in particle size distribution of the two aerosols.

Currently, measurement of clearance function in field studies is not possible. However, the effects of sulfuric acid and/or ozone on bronchial clearance can be assessed as changes in respiratory symptoms on a health diary in children.

Chronic exposures

Repetitive exposure to H_2SO_4 in donkeys and rabbits has produced persistent alterations in mucociliary clearance rates. Histological examination of the airways of exposed rabbits, have shown changes which account for the altered clearance and resemble those seen in human cigarette smokers and animals exposed to chemical irritants, Schlesinger (1985a). The dose-response trends observed for H_2SO_4 effects on bronchial clearance parallel those studies conducted with cigarette smoke, a known causal factor in the complex etiology of chronic bronchitis, Albert *et al.* (1974) and Albert *et al.* (1975). Bronchial clearance is markedly accelerated in both humans and donkeys exposed to the fresh smoke from several cigarettes. The chronic inhalation of smoke, as suggested by Albert *et al.* (1986), will produce excess mucus with continued increases in the level of secretions. This can result in over-loading of the transport system, retarding clearance and producing overt disease. Recent analyses by Schlesinger (1986) suggest that the effects of sulfuric acid is cumulative. Although direct evidence of an association between chronic low level exposures to H_2SO_4 and chronic bronchitis is lacking, a similarity in the mucociliary dysfunction shown for H_2SO_4 and cigarette smoke exposures provide suggestive evidence. Based on comparisons of the acute dose-response relationships in humans and animals, and the effects of chronic exposure in animals, it appears that chronic H_2SO_4 exposures of 100 ($\mu g/m^3$)-h per hour could produce persistent changes in mucociliary clearance in previously healthy individuals that yield dysfunction, which can play a role in the onset of chronic bronchitis and can change the effectiveness of the mucocilliary transport of pathogens from the lung, Schlesinger (1986).

Field Health Studies

As mentioned previously, the first field study by the NYU study team to examine ozone effects on children took place in 1980 in Indiana, PA, which is a town located east of Pittsburgh in Western PA. Lung function was measured in a summer day-camp program for 8- to 13-year-old children who had ambient exposures to O_3 and other air pollutants, Lippmann *et al.* (1983). Since this was a day-camp program, the children were accessible only on weekdays. The study was conducted during a summer with atypically low pollution levels for the Northeastern U.S. During the study, only O_3 approached current NAAQS values (240 $\mu g/m^3$), with a 1 h peak of only 220 $\mu g/m^3$. Despite the low concentrations, there were significant decrements in FVC and $FEV_{1.0}$ when the 220 $\mu g/m^3$ day was compared to days when the peak O_3 was 160 $\mu g/m^3$. On the days when the children's activity levels were most comparable, the decrement in FVC was about 6% with a O_3 concentration of 200 $\mu g/m^3$ versus a day with O_3 of 100 $\mu g/m^3$. A lesson learned from the Indiana study was that the level of physical activity had a major influence on the extent to which a dose response effect was observed in the children.

In 1982, a follow-up of the Pennsylvania study was conducted in Mendham, NJ, which is a low-density suburban town west of New York City. The effects of O_3 and H^+ on pulmonary function was studied in children attending a private summer day-camp, but the children in this camp were much less active than those studied in Indiana, PA. The children were only available for study on weekdays. As reported by Bock *et al.* (1985), linear regressions between the daily peak 1 h O_3 concentration for a given day and the corresponding FVC, FEV_1, and Peak Expiratory Flow Rate

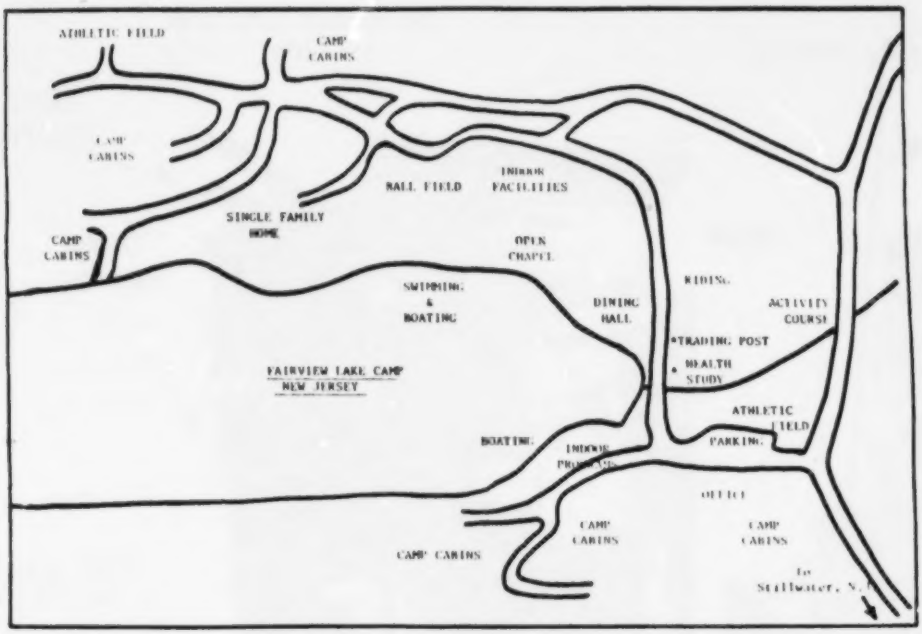

Fig. 1. Diagram of the Fairview Lake Summer Camp in Northwestern, NJ. (Note: Not drawn to scale.)

(PEFR) obtained from spirograms were determined for each of the 39 children tested on six or more days. The children's regression for PEFR showed most slopes to be negative. Mean slopes for each function were negative, except for FVC in boys, indicating a general tendency for decreased function with increasing O_3 concentration. In another analysis by Bock, *et al.* (1985), a summary weighted correlation coefficient between peak O_3 level and each pulmonary function parameter was calculated for each of 49 children seen on four or more days. Consistent with the regression analysis, decrements in PEFR were significantly correlated with the O_3 exposure.

Recent field health studies in Houston, TX, by Selwyn *et al.* (1985) have shown that O_3 produces short-term decreases in the pulmonary function of exercising adults at levels of ambient ozone which reached 270 $\mu g/m^3$. In a study by Ozkaynak *et al.* (1985) conducted in 1983 at Camp Couchiching, Ontario, the non-asthmatic children showed decrements in FVC, and FEV, for ozone and time lagged sulfate. Re-analyses of these data by adjusting for heart rate did not change the results or increase the power of the study, Kinney *et al.* (1986).

Lioy *et al.* (1985) extended the analyses of the spirometric data collected at Mendham, NJ in 1982 by examining the persistence of decrements in function following a period of five consecutive days of relatively high O_3. Analyses of the health data taken after this major ozone episode showed large average deviations in predicted PEFR obtained from the PEFR-O_3 regressions for the 2nd through the 11th day. The average deviation was about +5%. These appeared to be related to the effects and aftereffects of the prolonged period of high O_3 exposure which preceded the second week of study. In the first week episode, the 1 h peak ozone values each day were 286, 372, 330, 270, and 224 $\mu g/m^3$, and the concentrations were above 200 $\mu g/m^3$ for greater than 8 h on each day, which exceeded the occupational Threshold Limit Value (TLV). This period of exposure to elevated ozone appeared to have had a cumulative effect on PEFR, producing a shift in the magnitude of the average PEFR residual which persisted at least through the three low O_3 days when the children were available for measurement during the second week. The average deviations of the predicted PEFR on a given day were obtained from the regression equations for each child for temperature, relative humidity, H^+, NO_3^-, and SO_4^{2-} concentrations vs. PEFR. The regression results for H^+ and temperature also indicated a shift in the residual baseline for PEFR after a major episode, coincident with that associated with O_3.

The results of the Indiana and Mendham studies identified the need to have access to the children on every day of the study, not just weekdays. In the Mendham, NJ study, both an acute and a persistent effect were demonstrated as a result of episodes when the concentrations ranged from 40–370 $\mu g/m^3$ ozone and 0 to 7 $\mu g/m^3$ H^+ (as H_2SO_4). This was detected even when the study team did not have daily access to each child for pulmonary function measurements. Further,

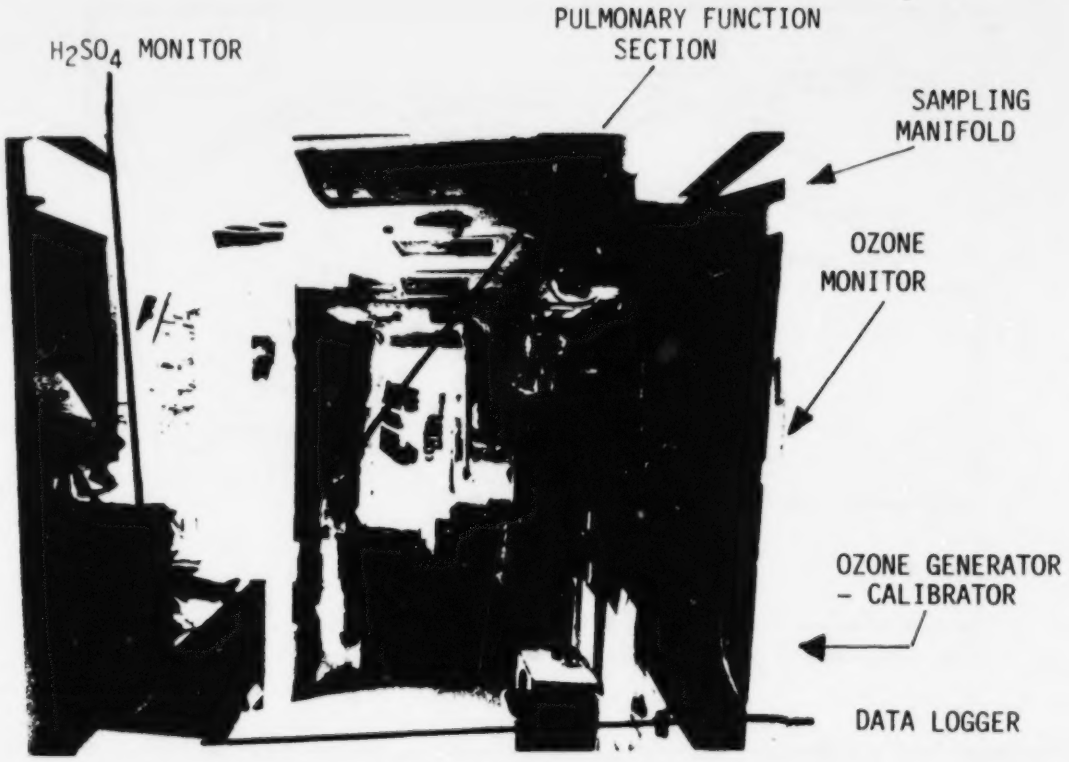

Fig. 2. Interior of mobile van.

the analyses of the children's function data were keyed only to the maximum ozone concentration during the period of the health measurements on each day. This was probably, in many cases, a surrogate for the intensity of exposure during that day. A more direct dose-response relationship would be obtained by recording the time of the test for a child and using the O_3 concentration measured in the hour or multiple hours just prior to the function measurement.

It is important to minimize exposures in places other than the camp environment. Living out of doors would not be a requirement since a one hour exposure to the irritants was shown to affect the respiratory system; however, episode-related effects can result from an accumulated dose of irritants. The number of indoor sources (e.g. smoking), should be minimized to reduce the number of confounders in assessments of the effects smog exposures on children.

Using healthy children minimizes the potential for losing a pulmonary response or symptom signal because of the over-riding effects of asthma or chronic lung disease. The Ozkaynak *et al.* (1985) study had both asthmatics and non-asthmatics, and consistent results could only be observed in the non-asthmatic children. The health studies also indicated that effects from ozone and multiple pollutants can be exacerbated by exercise which indicated the need to have a camp which included vigorous outdoor exercise programs. The use of children, especially in the age group from 7–13, also reduces the probability of having a large proportion of the subjects who are active smokers.

Approach to Fairview Lake Study

As a result of the preceding discussion, the Fairview Lake study used: (1) spirometry to assess both timed volumes and flow components, and other lung function variables; (2) children selected from the resident population at a rural New Jersey camp, (3) an air pollution exposure evaluation program which was concerned primarily with developing exposure profiles to hydrogen ion (strong acid) content of the ambient aerosol, ozone, and sulfur dioxide, (4) a field protocol conducted continuously over a four-week period in summar to obtain information on a variety of atmospheric conditions, and (5) the results and experiences derived from the Indiana, PA, and Mendham, NJ, studies to minimize operational errors.

To obtain the best information on ozone-dose response and the maximal opportunity to be influenced by an episode, the study was conducted seven days a week in July and the early part of August. All environmental and health measurements were made at the same location; both types of instrumentation was housed in a

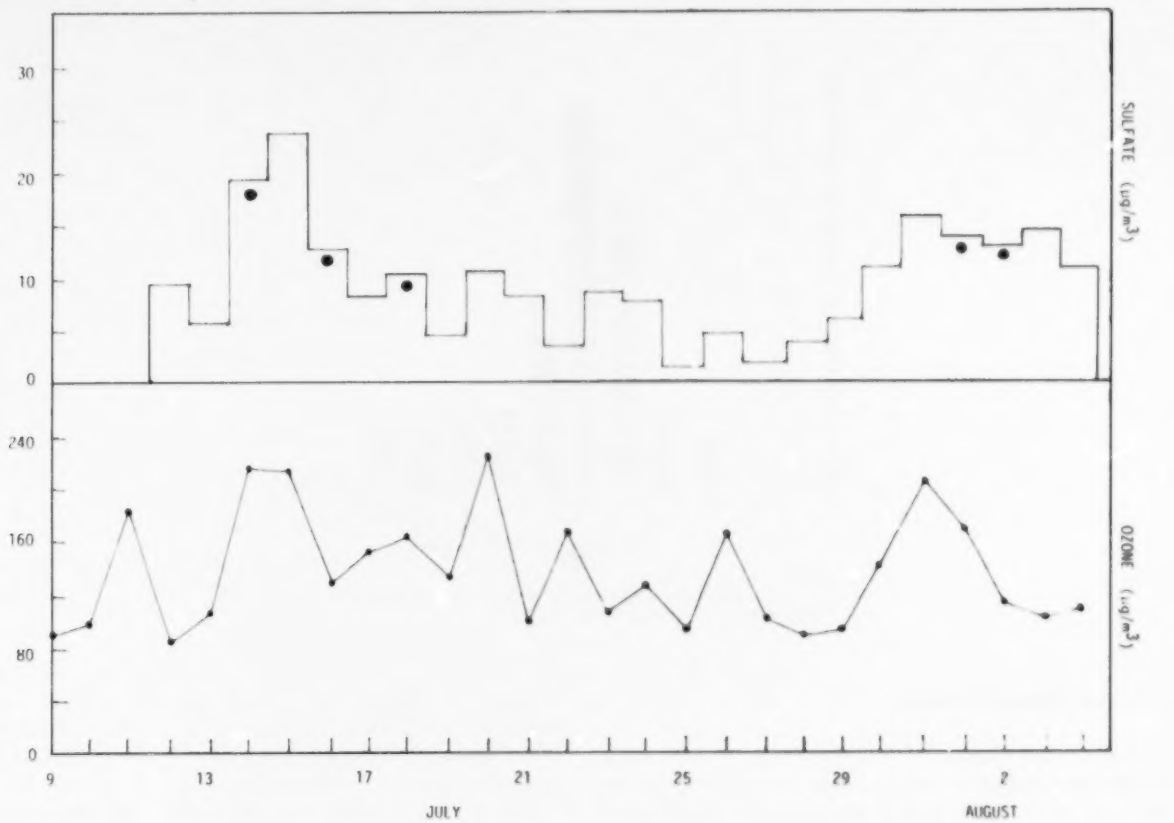

Fig. 3. Daily variation of (A) four-hour average sulfate ion, and (B) one-hour maximum ozone concentration at Fairview Lake, NJ, during the summer of the 1984 health study. (Key: ● H_2SO_4 present in atmosphere.)

mobile van on loan from the Environmental Protection Agency. The front portion of the van was redesigned to house the environmental monitoring equipment. The back half, which had a rear access door, was used to make the function measurements.

The camp was operated by the YMCA and is located in Northwestern NJ, at Fairview Lake, Fig. 1. It was close to ideal for this investigation for several reasons:

(a) It is within that part of the Northeastern U.S. which normally has high concentrations of O_3 and SO_4^{2-} during summer photochemical smog episodes. Previous data from the Chester, NJ, monitoring site, located 25 km to the east, indicated that ozone concentrations in excess of 240 $\mu g/m^3$ and SO_4^{2-} concentrations in excess of 20 $\mu g/m^3$ could be expected in the area during the summer.

(b) It is within a subregion which is not greatly affected by local sources of anthropogenic pollutants. The nearest sources are in the moderately sized town of Newton, NJ, which is to the northeast of the site. Thus, if children exhibit any measurable health effects during or after the passage of the hazy air masses, there will be a minimum of alternative or secondary causal pollution sources to complicate the interpretation of the impact of the transported pollutants.

The camp had between 100–150 children enrolled each week in the summer program but some were beyond the acceptable age limits. The campers participated in minimal indoor activities and slept in cabins which were ventilated solely by natural draft through screened windows. Permission for access to the children was readily obtained from the governing board of the YMCA. Enrollment was between 40–50% over the four weeks of study after suitable orientation and background were provided. Some children were signed up for the study after they arrived at camp and noticed that many fellow campers were involved. The parent or guardian of each child was sent a letter detailing the study, and a consent form. Most rejections of the offer to participants were because the parents felt the tests could disrupt camp activities. The population selected in Fairview Lake YMCA were the active-healthy summer campers.

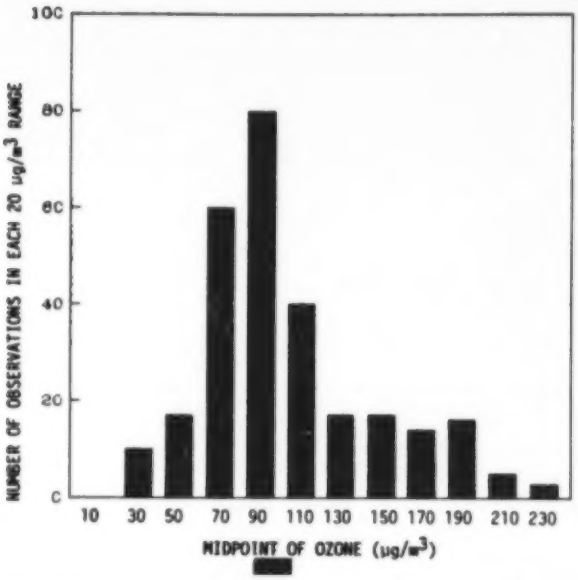

Fig. 4. Frequency distribution of one-hour ozone concentrations at Fairview Lake, NJ, July–August, 1984.

Function Measurements

Ninety-one children (53 boys and 38 girls) who were in full-time residence at the camp and participated in the study provided at least 7 days of valid spirometric data. Thirty-four participated for the first 2 weeks only, and 20 for the last 2 weeks of the study between July 8 and August 4, 1984. Their ages ranged from 7 to 15 years. Their homes were mainly in Eastern New Jersey and other locations in the Metropolitan New York region. The ethnic composition of the groups was 72 White, 15 Blacks, 3 Asians, and 1 Hispanic. For each child, an informed consent was obtained from a parent or guardian who completed a standardized respiratory symptom of the approximately 50% completing the questionnaire, three children were asthmatics, and of these three would wheeze upon exercise. Nine children had severe chest illness before the age of two, including two of the asthmatics. At some point during the course of the study, each child was measured for height and weight. The activities of the study team were coordinated with the daily schedule of each age group. A liason was established between the study team and the camp counselors to ensure maximum participation. Daily activity included swimming (lake), boating, horseback riding, softball, tennis, and hiking. At the study's end, each child received a t-shirt and a certificate for participating in the study.

Measurements of pulmonary function were made on most children on every day of their stay in camp. Of the children who participated in the study for four weeks, one participated for 26 days and most were > 22 days. The measurements were done inside a mobile laboratory, Fig. 2, which housed all equipment. The measurements were performed between 11:30 a.m. and 6:30 p.m., during breaks in a child's program of activities or during free periods.

On each daily visit to the mobile laboratory, the children underwent three types of examinations: (1) answering a simple symptoms questionnaire, (e.g. hoarseness, sore throat, cough, phlegm, chest pains, wheeze, runny or stuffy nose, or eye irritations); (2) measuring peak expiratory flow using a mini-Wright peak flow meter, for which three values were recorded; and (3) performing spirometry tests on a manual 8L Collins portable recording spirometer in a sitting position with a nose clip. Two identical spirometers were used for simultaneous measurements on individual children. Each spirometer volume was calibrated daily using a standard 31 syringe. Atmospheric pressure, room temperature, and time of day were recorded for each test. The spirometry test consisted of a minimum of three ATS criteria, Snowbird Workshop (1979), acceptable forced maximal expiratory maneuvers yielding volume-time tracings. The acceptance criteria for the three best FVC (forced vital capacity) values were that for (1) the FVC should not vary by more than 200 mL; (2) each curve rise time should be smooth and start from at most 200 mL; (3) each curve should have no bumps or dips; (4) each curve must last for at least 4 seconds, and (5) each curve must reach a plateau that lasts at least 1 second. From the three best tracings made by each child each day, the following parameters were determined: Forced Vital Capacity (FVC), Forced Expiratory Volume in 1.0 second ($FEV_{1.0}$), Forced Expiratory Flow between 25% and

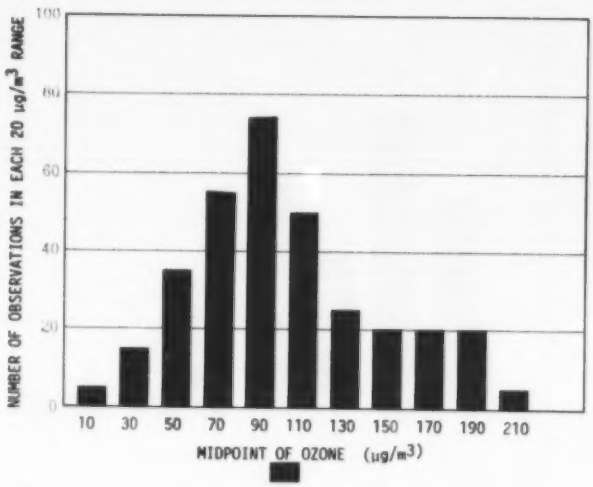

Fig. 5. Frequency distribution of four-hour ozone concentrations at Fairview Lake, NJ, July–August, 1984.

75% of Vital Capacity ($FEF_{25\%-75\%}$) and Peak Expiratory Flow Rate (PEFR).

Each tracing was analyzed twice by independent readers, and the results stored in computer files for further selection of the best test for use in the statistical analysis of the health and environmental data. All environmental data to be used were keyed to the time that a child performed the pulmonary function test. Files also were designed to handle the medical history and other characteristics of each child.

Exposure measurements

The exposure data from the Fairview Lake study have been assembled. The major features of the study period are described with an emphasis on how the characteristics of the pollution patterns at site satisfied the needs of the study design to examine the effects of photochemical smog.

Methods

All data were collected from the EPA mobile van which was situated in the center of the camp and which allowed for easy access by the children during the day. The location was away from any commercial or local street traffic, but was next to a dirt road, which was watered as necessary to keep dust to a minimum. The only traffic were occasional delivery trucks and camp vehicles.

The ozone data were collected continuously with a Dasibi UV photometer (1003-AH). Instrument specifications and baseline checks were completed daily using a dynamic calibrator that had a quality-assured UV and zero air source. Full multi-point calibrations of the monitor were conducted weekly, and an independent quality assurance test was completed by the New Jersey Department of Environmental Protection at the end of the study. The monitors agreed to within 10% of the test concentrations.

The sulfuric acid, total particulate sulfur and ammonimum salts measurements were made using a quasi-continuous (15 minute cycle) thermal analysis flame photometric detection system modified by Allen *et al.* (1984). Sulfur dioxide calibrations were made every three to five days, and H_2SO_4 aerosol calibrations were conducted prior to and after the study.

Since the ammonimum bisulfate concentration cannot be discriminated from $(NH_4)SO_4$ directly by the H_2SO_4 monitor, it was estimated for the 9 a.m. to 6 p.m. period of each day from the total hydrogen ion H^+ filter samples collected for the fine particle fraction ($d_{50} = 2.5\ \mu m$) by a dichotomous sampler which operated from approximately 10 a.m. to 2 p.m. and 2 p.m. to 6 p.m. Each filter was removed from the sampler, placed immediately in extraction solution and refrigerated until shipment to an independent laboratory for analysis. The NH_4HSO_4 concentration was subsequently estimated from the molar equivalent differnce of the H^+ in H_2SO_4 obtained from the quasi-continuous analyzer and the total H^+ measured on the filters for the same sampling period. The actual methodology is detailed in a study by Morandi *et al.* (1983).

The children were measured for lung function from 11:30 a.m. until 6 p.m. The daily maximum 1 h and 4 h average ozone concentrations always occurred during this interval during the study, as well as most peaks in H_2SO_4. For the latter, H_2SO_4 concentrations above 2 $\mu g/m^3$ were observed in the late evening and early morning during August 1 and August 2. The daily variation in the 1 h ozone maximum and the 24 h average of total sulfur are shown in Fig. 3. The maximum ozone concentration was 226 $\mu g/m^3$ and occurred on July 20. Five days prior to this date there was a two-

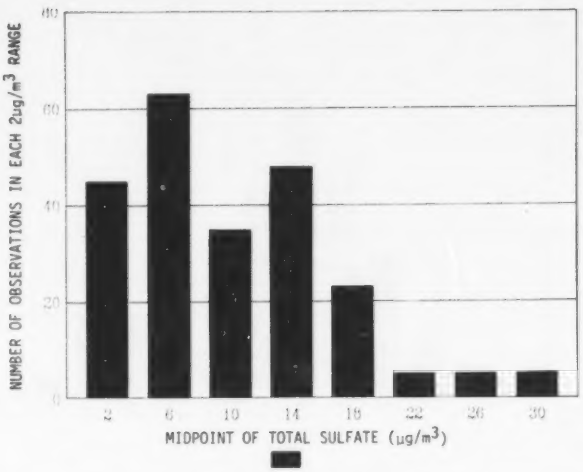

Fig. 6. Frequency distribution of one-hour total sulfur concentrations at Fairview Lake, NJ, July–August, 1984.

day episode during which the 1 h maximum ozone reached above 200 $\mu g/m^3$, and, as is usually the case during summertime episodes, the particulate of sulfur levels increased to above 20 $\mu g/m^3$. This increase in SO_4^{2-} did not occur on July 20. The ozone levels again reached above 200 $\mu g/m^3$ eleven days later on July 31. The total sulfur levels (as sulfate) also increased to 15.8 $\mu g/m^3$. In contrast to the earlier period, the ozone levels dropped 100 $\mu g/m^3$ by July 31, but the sulfate levels and NH_4HSO_4 remained between 12 and 15 $\mu g/m^3$ for the remainder of the study. H_2SO_4 persisted at levels of about 2 $\mu g/m^3$ and 6 $\mu g/m^3$, respectively, throughout the period from July 31 through August 3, Lioy and Lippmann (1986).

The preceding results indicate a variety of possible population exposures to irritant species. These include study days with and without the simultaneous occurrence of high ozone and acidic sulfate species. The former occurred during the first two weeks, and the later in the last week. Thus, in addition to the planned dose response studies, the health data can be examined for the way the different O_3 and H_2SO_4 accumulation patterns may have affected the children.

To obtain a more complete picture of the ozone and H_2SO_4 exposures over the entire study for the interval from 9 a.m. to 6 p.m., the frequency distributions of the 1 h and 4 h ozone averages and the 4 h averages of H_2SO_4 and NH_4HSO_4 are presented in Fig. 4 through 8. For ozone, it is apparent that there was a log-normal distribution with a median of about 80 $\mu g/m^3$. There were no violations of the 240 $\mu g/m^3$ NAAQ standard at the site during the July and August study, but there

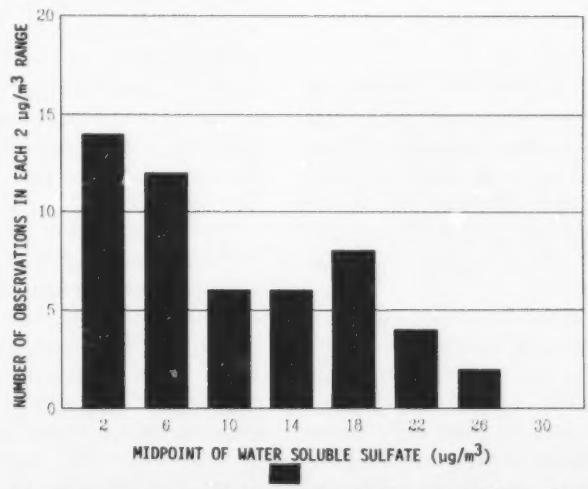

Fig. 7. Frequency distribution of four-hour water soluble sulfate concentrations at Fairview Lake, NJ, July–August, 1984.

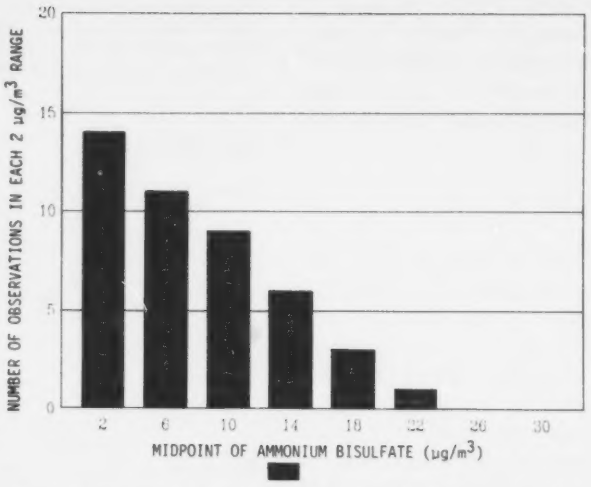

Fig. 8. Frequency distribution of ammonium bisulfate concentration (estimated) at Fairview Lake, NJ, July–August, 1984.

were twenty-one 1 h averages above 180 $\mu g/m^3$. The range in 1 h averages were from 22 to 226 $\mu g/m^3$ with two consecutive hours of O_3 at 226 $\mu g/m^3$ occurring on July 20. On that same date, the 4 h average exceeded 202 $\mu g/m^3$. As would be expected, the distribution of the running 4 h average ozone concentrations were lower than the 1 h averages. However, there were still twenty-four intervals in which the average of four consecutive hours was above 160 $\mu g/m^3$ and thirteen in which there was four consecutive hours above 180 $\mu g/m^3$. The 4 h average SO_4^{2-} measurements showed a very flat distribution. This was probably due to fewer data points, since only two 4 h integrated samples were taken by the dichotomous sampler in the period from 9 a.m. to 6 p.m. When the total sulfur values (SO_4^{2-}) for the same interval were plotted, Fig. 9, the particulate sulfur data showed a bimodal shape (one mode between 4 and 6, and another between 12 and 14 $\mu g/m^3$). Since there are no local sources near the site, the two concentration modes suggest the presence accumulation patterns during the non-episode and episode conditions, respectively. The latter would represent the impact of regional smog and mesoscale plume products. The acidic species associated with the SO_4^{2-} do not show an equivalent concentration pattern. For instance, the 4 h average H_2SO_4 levels were usually low, between 0 and 0.5 $\mu g/m^3$, while on five occasions the values were between 3.5 and 4.5 $\mu g/m^3$ (11% of the values). Also, there were one-hour spikes above 5 $\mu g/m^3$. The NH_4HSO_4 concentrations, however, showed a different distribution pattern. In this case the levels were distributed normally throughout the study

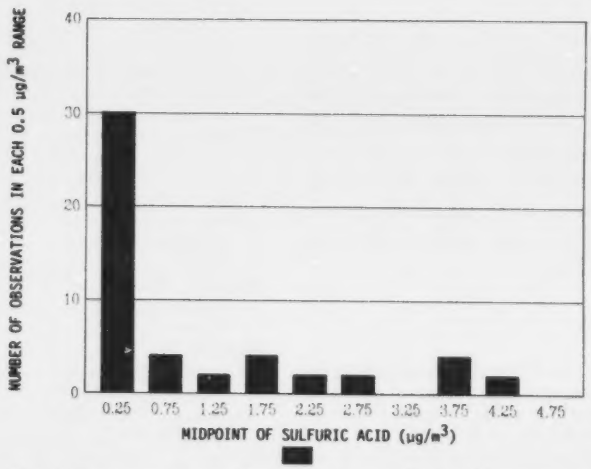

Fig. 9. Frequency distribution of four-hour sulfuric acid concentrations at Fairview Lake, NJ, July–August, 1984.

and ranged from 0.5 to 20 $\mu g/m^3$ with a mean of 7.9 $\mu g/m^3$. It is apparent from the data that in Fairview Lake the acidic species concentration distribution was different from the SO_4^{2-} distribution, and also differed from the log normal ozone distribution found at this site.

Summary

Based upon the results of previous studies, the Fairview Lake study design has taken into account the need to measure lung function of the children on a seven-day week schedule throughout an entire month. This was accomplished for about one third of the children with the remainder staying for either the first two weeks or the last two weeks of the study. The terminations were due to the duration of a child's stay in camp and not disenchantment with the study. The use of a seven-day health measurement protocol minimized the possibility of missing important pollution related events. This was further enhanced by having a camp in which there were minimal indoor activites, but significant periods of outdoor exercise during the day. As per previous studies, the measurement of pulmonary function was used to focus on ozone effects and synergistic effects of acid, while the symptom diary was used as an indicator of any effects related primarily to acid exposure.

Because of the nature of the pollution accumulation pattern, the segregation of the children into groups may prove to be beneficial, since the first two-week group was exposed to a typical ozone-sulfate episode, although only moderate levels of ozone accumulated. The later two-week group was affected by low but persistent levels of acidic species during the last four days of their stay. In all cases, the number of confounding pollution variables were minimized, since there were no indoor sources present to significantly affect the O_3 and H_2SO_4 exposures received by the children.

The concentrations observed for O_3 were probably sufficient for further examining the ozone-pulmonary function acute response relationship observed in the Indiana, PA, and Mendham, NJ, studies. The ability to discern persistent effects may be difficult to assess because of the absence of persistent ozone exposures. Since, as stated above, there was one minor ozone episode in the beginning of the study, and a strong acid episode over the last four days.

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